METAS TIME & FREQUENCY METROLOGY REPORT

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Abstract

METAS is the NMI for Switzerland. The Time & Frequency Laboratory (TFL) is responsible for the generation and dissemination of precise time and performs calibrations for customers. This paper reports on current or recent activities and international collaborations.

INTRODUCTION

METAS is the National Metrology Institute (NMI) for Switzerland. The Time & Frequency Laboratory (TFL) is responsible for the generation and dissemination of precise time in Switzerland, for the maintenance of the national metrology standards, and for the delivery of calibration services to the industry.

The TFL operates a hydrogen maser and four commercial cesium clocks, which are used to generate the UTC (CH) and TA (CH) time scales. The atomic clocks also contribute to the generation of TAI and UTC. A TWSTFT link is used to connect UTC (CH) to UTC and TAI. In addition, two calibrated GPS links are operated as backups for the TWSTFT link.

TIME DISSEMINATION SERVICES

METAS operates a cluster of three redundant stratum-1 NTP servers, all traceable to UTC(CH). The stratum-1 servers are not reachable from the Internet. However, a pair of stratum-2 NTP servers referenced to the stratum-1 cluster are offered to free public access (*ntp11.metas.ch* and *ntp12.metas.ch*).

METAS also offers an Automated Computer Time Service (ACTS), which is similar to the NIST ACTS, but based on the European standard ITU-R TF 583.2.

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Moreover, METAS operates HBG, the Swiss VLF 75 kHz time signal transmitter. METAS became the operator of HBG in June 2000. Before that, HBG had been transmitting since 1966, first under the authority of the Swiss PTT, up to 1997, and then of Swisscom.

However, the Swiss government has recently decided to decommission the HBG transmitter at the end of 2011 because the maintenance costs are too high. After 2011, receivers and services that rely on the HBG transmitter will have to be modified to receive the signal from the German VLF 77 kHz transmitter DCF. Technically, the DCF and the HBG signals are compatible except for the carrier frequency.

CALIBRATION SERVICES

METAS offers time and frequency calibration services similar to the services offered by other NMIs. For example, we calibrate quartz oscillators and atomic frequency standards, as well as radio-controlled frequency standards. Recently, we had the opportunity to perform the differential calibration of the internal delays of geodetic P3 GPS receivers. A list of the standard calibration services of METAS is available on *www.metas.ch*.

TWSTFT AND GPS LINKS

METAS has been equipped with a Two-Way Satellite Time and Frequency Transfer (TWSTFT) terminal since 2007. After the first calibration of the METAS-PTB link, the TWSTFT link became the official TAI link in July 2007.

The most recent link calibration was performed in September 2008. The current accuracy of the METAS-PTB pivot link calibration is ±1.1 ns. Originally, the link was driven by a free-running hydrogen maser. However, since June 2009, the link is driven directly by UTC (CH).

METAS also operates two geodetic GPS receivers (Ashtech Z-XII-T and Septentrio PolaRx2TR) that are used as backups for the main TAI link.

UTC (CH)

UTC (CH) has been defined as a steered Master Clock (MC) since November 2007. Before, it was defined as a paper time scale. The design and the successive phases of development of the new time scale generation system were reported at the PTTI conference and elsewhere **[1-3]**. A block diagram is shown on Figure 1.

The main characteristics are as follows. There are two redundant master clocks, MC-A and MC-B. MC-A is driven by a hydrogen maser, while MC-B is driven by a cesium frequency standard. A pair of switches allows the selection of either MC-A or MC-B as the source of the UTC (CH) 1-PPS and 5-MHz signals. The switches are used to automatically switch from the main to the backup master clock in case of failure or for the purposes of maintenance.

A pair of redundant multi-channel 5-MHz phase comparators is used to continuously compare the atomic clocks, an ensemble of four commercial cesium standards and a hydrogen maser. A paper time scale is generated from the clock ensemble and each of the master clocks is independently steered to the paper

time scale. The time constant of each master clock internal steering control loop is adjusted to optimize the short-term stability of the master clock, depending on the characteristics of the reference used. The main master clock MC-A has the best short-term stability, because it is driven by a hydrogen maser. The paper time scale is steered periodically to track UTC. Since both master clocks are steered to the same paper time scale, they are never far from each other, and when UTC (CH) is switched from one master clock to the other, the only observable discontinuity is a step of the short-term stability level.

Figure 2 shows the complete history of UTC – UTC (CH) published in the BIPM data base. Figure 3 shows the recent history (2009) of UTC – UTC (CH). Note that in 2009 only four steering maneuvers (MJD 54905, 54978, 55094, 55122) were applied in order to track UTC within a range of ± 20 ns.

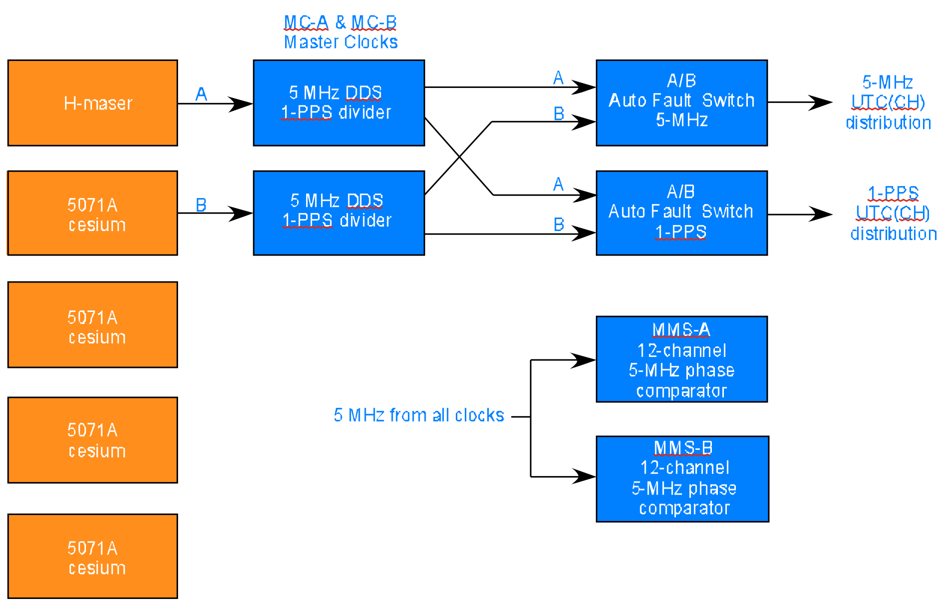

Figure 1. Block diagram of the UTC (CH) generation process.

During the summer of 2009, precisely from 2009-06-08 MJD 54990 to 2009-09-04 MJD 55078, UTC (CH) was temporarily switched to MC-B in order to perform some necessary maintenance on the hydrogen maser which normally drives MC-A. During this period, MC-A was driven by a cesium reference and kept in standby as a backup. This is a good example of the use of the redundant master clocks to allow maintenance of pieces of equipment without an interruption of service.

Figure 4 shows the TWSTFT measurements taken from the METAS-PTB link during and after the maintenance of the hydrogen maser. It can be observed that on 2009-09-04 MJD 55078, when UTC (CH) is switched back from MC-B (cesium-driven) to MC-A (maser-driven), the time discontinuity is negligible. However, an improvement of the short-term stability can be observed.

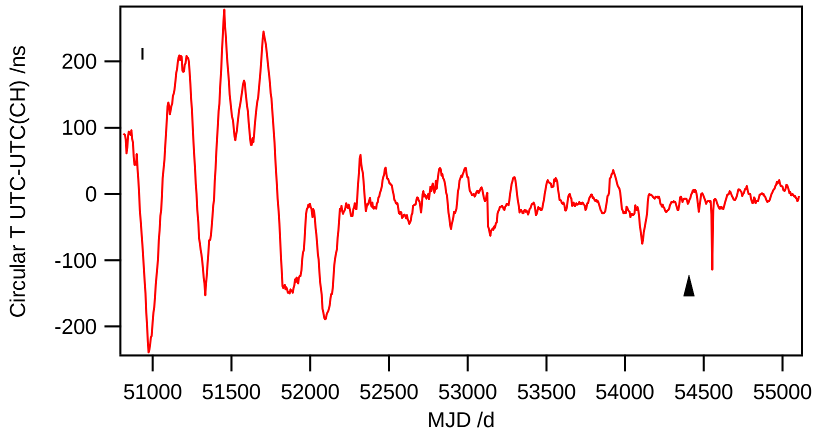

Figure 2. History of UTC – UTC (CH) as published in BIPM data base. Marker indicates November 2007 when the steered master clock definition of UTC (CH) was introduced.

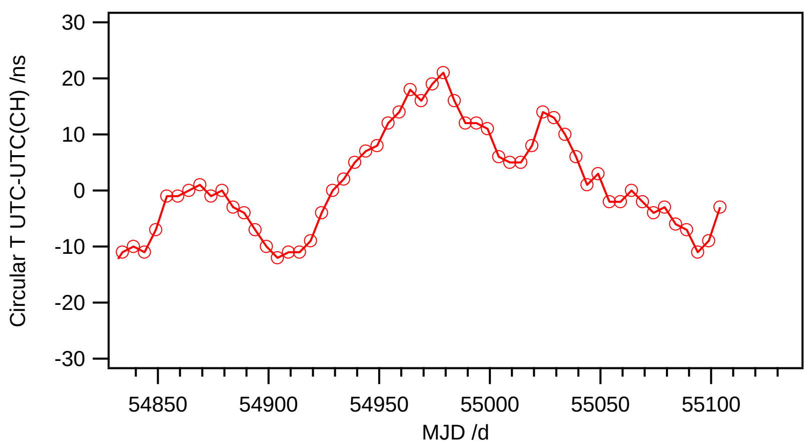

Figure 3. UTC – UTC (CH) in 2009 as published by BIPM in Circular T.

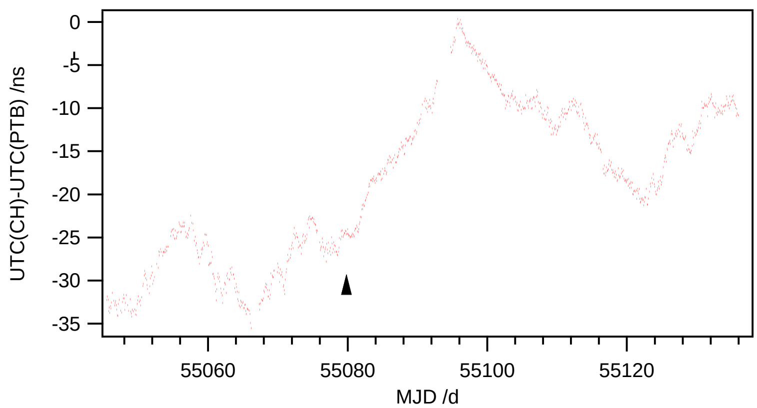

Figure 4. TWSTFT measurements UTC (CH) – UTC (PTB) /ns from the METAS-PTB link. Marker indicates 2009-09-04 MJD 55078 when UTC (CH) was switched from MC-B (cesium-driven) to MC-A (hydrogen-maser-driven) after maintenance of the hydrogen maser. Observe the improvement of the short-term stability after switching to MC-A.

PRIMARY STANDARDS

FOCS-1 **[4]** is a primary frequency standard based on a continuous beam of cold cesium atoms, developed in collaboration with the *Laboratoire Temps Fréquence* (LTF) of the University of Neuchâtel. The design and partial results have been presented on various occasions. The short-term stability of $3 \times 10^{-13}\,\tau^{-1/2}$ is only limited by the signal-to-noise ratio of the currently available atomic flux. METAS and the LTF collaborate also on the construction of a second continuous fountain standard FOCS-2. FOCS–2 is an improved version of FOCS–1, including a 2D–MOT pre-source and a more efficient transverse cooling scheme, both designed to increase the atomic flux by a factor of 40 **[5]**. The goal of this second instrument is to achieve lower short-term instabilities through a higher atomic flux obtained by implementing those two techniques. In a continuous fountain, contrary to a pulsed fountain, the lasers must remain on at all times and some light can be scattered in the free flight region of the atoms, shifting the clock frequency ($+1.2 \times 10^{-12}$ measured in FOCS–1). To suppress the light-shift systematic error, a continuously rotating light-trap, driven by an electrostatic motor and blocking the light but not the atoms, was developed and implemented **[6]**.

The effect of aliasing or inter-modulation on the frequency stability of continuous fountains was also evaluated. By deliberately degrading the phase noise performance of the local oscillator, it was possible to demonstrate experimentally a substantial removal of the inter-modulation effect **[7]**.

Recently an unexpectedly high end-to-end phase shift was observed on FOCS-1 and the microwave cavity is currently under investigation.

INTERNATIONAL COLLABORATIONS

Since 2007, the combined availability of a calibrated TWSTFT link, multiple calibrated GPS links, and a hydrogen-maser-driven master clock qualifies METAS as an attractive location to perform time & frequency transfer experiments with the GPS and TWSTFT links.

The improved technical infrastructure has created new opportunities for international collaboration. During the summer of 2008, Gérard Petit of BIPM visited METAS to perform time & frequency transfer experiments with different types of GPS receivers and several data processing techniques **[8]**. In 2008, we also collaborated with PTB to prepare for an impending change of satellite that affected the TWSTFT community **[9]**. Moreover, in the summer of 2009, we had the visit of Thorsten Feldmann, a PhD student from PTB, who performed a GPS receiver calibration experiment between METAS and PTB with the goal of evaluating the actual achievable accuracy of the calibration of GPS receivers. The results of this experiment will be published shortly.

CONCLUSION

With the help of the new steered master clock definition of UTC (CH) and of the calibrated TWSTFT TAI link, METAS is now capable of performing time measurements with an accuracy of ± 1.6 ns, limited by the UTC – UTC (CH) uncertainty, which includes the METAS-PTB link calibration uncertainty.

On the other hand, the statistical part of the UTC – UTC (CH) uncertainty, published in *Circular T,* is 0.6 ns, which implies that frequency calibrations versus TAI can now be performed with an accuracy of $U_y = 0.6\ \mathrm{ns}/T$, where T is the integration time. For an integration time of 10 days, the uncertainty is 7×10^{-16}.

These improved calibration capabilities are the welcome result of several years of development and troubleshooting and will be used at the benefit of METAS internal and external customers and collaboration partners.

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